TECHNICAL NOTES

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THE DRAG OF INFLATABLE RUBBER DE-ICERS

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SUMMARY

Force tests on rubber de-icer models of several different profiles, at approximately one-third full scale, have been carried out in the N.A.C.A. 8-foot high-speed wind tunnel. The conventional de-icer installation, deflated, added about 15 percent to the smooth-wing drag and, inflated, added about 100 percent. An improved installation with flush attaching strips added about 10 percent, deflated. The bulging, or ballooning, of de-icers from the wing surface is described and some remedies are discussed.

INTRODUCTION

Devices for preventing ice formation on aircraft must be judged not only for their efficacy in eliminating icing troubles but also for their effect on the performance of the aircraft. Although the first item is of primary importance, the second item is of considerable interest, especially since the de-icing installation normally affects the aircraft performance for a much longer period of time (generally all winter) than the period of actual use (perhaps 10 percent of winter flying time). The drag characteristics were investigated for the device most commonly used for ice removal in the winter 1937-38, the inflatable rubber de-icer. The drag of a normal installation, inflated and deflated, was determined, as was the drag of a proposed flush-type installation.

The N.A.C.A. 8-foot high-speed wind tunnel was chosen for the tests because the combination of a large test wing and a wide speed range permitted testing at large Reynolds Numbers. The equipment provided the opportunity of observing any peculiarities caused by high speeds, such as the fluttering and the bulging of de-icers in flight. Quantitative measurements were made of the bulging, and means of alleviating the condition were developed.

APPARATUS AND METHOD

The de-icer models were mounted on a smooth metal wing of N.A.C.A. 23012 section. The wing chord was 5 feet, and the wing assembly completely spanned the 8-foot-diameter closed throat of the wind tunnel. The rubber part of the de-icer was a 0.28-scale model of a 5-tube de-icer intended for wings of about 210-inch chord. It was found to be impracticable to make the metal attaching strips proportionately small so they were reproduced at 0.5 scale. When the variation of dimensions from one actual installation to another is considered, the scale of the model may be taken as one-third. The dimensions of the model de-icer are shown in figure 1.

For convenience, the inflated and deflated conditions of the de-icer were represented by separate installations. The installations representing the inflated de-icer were composites of wood blocks, to give the correct size and shape for the inflated tubes, and rubber covering, to give the proper surface conditions and profile between inflated tubes. This method simulates actual installations in flight except that in test the de-icer was prevented from deforming at the inflated tubes; whereas in service, with air pressure maintaining the de-icer profile, some deformation is possible at the higher speeds. This difference is not serious because it occurs only for the inflated condition when the de-icer drag is exceedingly high and therefore probably not sensitive to small changes.

This method of construction, of course, did not permit tests of the de-icer installation as actually operated by an air pump with the repeated cycle of: tubes deflated, two tubes inflated, two tubes deflated and three tubes inflated, then all tubes deflated again. Only a very small part of the cycle, however, is occupied by the transition from one condition to another, and the de-icer maintains each profile sufficiently long for the corresponding flow pattern to be well established. The drag throughout the whole cycle and the average drag can therefore be estimated from the present results for the condition of no ice.

The construction and attachment of the deflated de-icers were the same as in service except that, as noted later, some of the final forms were cemented to the wing for a better comparison of the various profiles at high speeds. Figure 1, illustrating the constructions used to simulate the de-icer profiles tested, represents the normal installation (a) with three tubes inflated, (b) with two tubes inflated, and (c) with all tubes deflated; and (d) a proposed flush-type installation, both with the normal de-icer surface (somewhat irregular owing to the varying thicknesses of rubber used and the fact that the tubes do not lie perfectly flat), and (e) with a de-icer surface having irregularities eliminated. The attaching strips in the last two cases were recessed as far as practicable into the wing surface. A few additional tests investigated methods of reducing the bulging or the ballooning of de-icers at high speeds and showed the effect of giving the rubber a high gloss finish.

The de-icers were tested at air speeds from 70 to 380 miles per hour. The range depended on the particular model, the maximum range corresponding to Reynolds Numbers from 3,000,000 to 16,000,000. Tests were made only at lift coefficients of 0, 0.15, and 0.3 to cover the range of high-speed flight. Air flow in the test section of the tunnel is sufficiently uniform and steady that any errors arising from these sources are insignificant. The turbulence, as measured by sphere tests, is approximately equivalent to that of free air.

RESULTS AND DISCUSSION

The results of the tests are discussed in terms of the increase in wing drag resulting from the installation of a de-icer. This increase is called the "de-icer drag" and is expressed as a percentage of the smooth-wing drag determined in the full-scale wind tunnel (reference 1) and in the high-speed tunnel. The air flow was approximately two-dimensional over the wing; the changes may therefore be considered as changes in the airfoil section characteristics. Table I summarizes the results for the three lift coefficients. The results for $C_L = 0.15$ are taken as typical and are used as a basis for drawing general conclusions.

Tests 1 and 2 ($C_L = 0.15$) indicate that the wing drag was approximately doubled for the condition of inflated de-icers. Test 3 is for the normal installation of a deflated de-icer and indicates the detrimental effect, on the basis of drag, of present-day installations at speeds below 200 miles per hour as well as the more unfavorable effect of localized bulging or ballooning of the de-icer away from the wing surface at higher speeds. The bulging was detected by visual observations of the de-icer during test; it will be seen that the drag changes correspond with the observed changes in de-icer profile. Figure 1(c) illustrates the size and the position of the bulges for $C_L = 0.15$. For $C_L = 0$, a bulge appeared only in the lower position and, for $C_L = 0.3$, only in the upper position. A comparison of the theoretical pressure distribution about the wing with the positions at which bulging started indicates that the bulges appeared, for the three angles of attack tested, at or near the peak negative pressure points on the de-icer. The magnitude and location of the peak negative pressures are as follows:

C_L	Peak pressure coefficient, $P = p/q$	Location
0	-0.7	Lower surface, 0.01c
.15	-.2	Upper surface, 0.03c
	-.3	Lower surface, 0.02c
.3	-.5	Upper surface, 0.03c

When the peak negative pressure coefficient is multiplied by the dynamic pressure of the air speed at which bulging occurred, the result indicates the bulging began when the local static pressure reached a value 40 to 70 pounds per square foot below the free-stream value. These relations, using available theoretical pressure distributions (reference 2), may be used for predicting bulging on any wing throughout its range of speeds and attitudes; these predictions agree with reported experiences including both landing and high-speed conditions.

The deformed de-icer reduces the local pressure still further at the bulge, thus making the process somewhat unstable. A remedy for this condition appeared to be the venting of the air pocket under the bulge to the negative pressure just outside the bulge on the theory that, with equalized pressure, there would be no tendency to form a bulge. Venting was tried, with 1/16-inch-diameter holes at 2-inch intervals on a line along which the bulge formed, but with no success. The drag results were the same as for test 3, and the bulges formed at the same air speed. An additional test was made with the vent holes open and with each end of the de-icer sealed, to be sure that the vent holes were not being required to handle such a quantity of air that pressure equality was not reached beneath and above the de-icer, but with no greater success. Increasing the initial tension of the de-icer installation raised the air speed at which bulges appeared, as would be expected, by about 50 miles per hour as shown by test 4. Backing the rubber "elastic area" between the tubes proper and the attaching strips with a fabric that stretched very little, thus making the only elastic area that of the five tubes, raised the air speed at which bulges appeared another 50 miles per hour as shown by test 5.

The initial tension of the three deflated de-icers with normal attachments is not accurately known on account of the snubbing action around the leading edge of the wing but some idea of the magnitude of, and the changes in, the tension may be gained from load-deflection curves for each of the de-icer models and from the known stretch (1/4 inch) for each model. The estimated tensions were:

Test	Condition	Tension (lb. per inch span)	Increase (percent)
3	Normal tension	0.5	0
4	Increased tension	.63	26
5	Fabric backing	.86	72

The local pressures at which bulging occurred for these three conditions averaged 60, 90, and 120 pounds per square foot, respectively, below stream static pressure.

The flush-type attachments were first tested in conjunction with the normal de-icer having a slightly irregular surface. The rubber, as in all the rest of the tests with flush-type attachments, was cemented to the wing to eliminate changes in profile due to bulging so that drag comparisons with other profiles should be made only for air speeds at which there is no bulging of the profiles. Test 6 indicates that substitution of the flush-type attachment decreased the drag 2 to 6 percent. In test 7, a rubber sheet of constant thickness was substituted for the normal de-icer rubber of varying thickness with the result that the drag was further reduced 2 to 7 percent for the speed range indicated. The net result of using flush-type attachments and eliminating the irregularities of the rubber surface (compare tests 5 and 7) was a drag reduction of 5 to 13 percent, leaving de-icer drags of 7 to 10 percent of the smooth-wing drag. It will be seen that the drag caused by the installation of test 7 was still appreciable. The rubber surface was smooth but gave the impression by feel that its friction coefficient was higher than that of polished paint or metal; its surface was therefore coated with dope to produce a glossy surface with a feel of low friction to determine if the original surface was responsible for some of the residual drag. The results of test 8 indicate that there was no effect of surface roughness.

The residual drags of 7 to 10 percent shown by tests 7 and 8 must therefore be due to the slight increase in the nose thickness resulting from laying rubber over the original profile and to the slight discontinuity at the attaching strip. Unpublished data from the high-speed tunnel indicate that very small discontinuities on the nose portions of smooth wings in air flow of low (approximately atmospheric) turbulence cause a disproportionately large drag increase, supposedly by disturbing the laminar flow over a portion of the wing. The final results here also indicate the importance of eliminating, to as great a degree as possible, any irregularities or discontinuities in de-icer or attachment profile.

The foregoing discussion indicates that the de-icer drags presented here are applicable only to installations on smooth wings, that is, on wings with no projecting rivet heads, surface roughness, protuberances, or discontinuities in surface contour, such as sheet-metal laps. The more irregularities on a wing, especially near the leading edge, before the installation of de-icers, the less will be the drag increase due to the installation. It is conceivable that a row of rivets near the leading edge, or some other protuberance, may be causing so much disturbance that the addition of de-icers may cause no increase in the disturbance and hence no added drag. In the results presented here, however, the effects of the de-icer profile are not masked by other disturbances, the complete effect of the change in profile due to the addition of a de-icer is indicated, and the drag increases presented are applicable to the basic, and ultimately desirable, case of a smooth wing.

CONCLUSIONS

1. Drag additions caused by a normal, deflated de-icer were from 13 to 29 percent of the smooth-wing drag, depending on the speed and attitude of the wing.

2. For the inflated conditions, the drag additions were of the order of 100 percent of the smooth-wing drag.

3. Beneficial results were obtained both by eliminating the irregularities of the deflated de-icer surface and by making the attaching fittings as nearly flush as possible. The drag additions were then from 1 to 19 percent.

4. Fluttering and bulging of rubber de-icers were experienced when they were subjected to negative pressures of the order of 60 pounds per square foot. The critical speed was raised as much as 100 miles per hour by increasing the tension in the rubber and backing the rubber with fabric.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 8, 1938.

REFERENCES

1. Jacobs, Eastman N., and Clay, William C.: Characteristics of the N.A.C.A. 23012 Airfoil from Tests in the Full-Scale and Variable-Density Tunnels. T.R. No. 530, N.A.C.A., 1935.

2. Garrick, I. E.: Determination of the Theoretical Pressure Distribution for Twenty Airfoils. T.R. No. 465, N.A.C.A., 1933.

TABLE I. De-icer Drag

Test	De-icer profile: Attachment	De-icer profile: Rubber	$C_L = 0$					$C_L = 0.15$						$C_L = 0.3$				
		Air speed, m.p.h. ⟶	100	150	200	250	300	100	150	200	250	300	350	100	150	200	250	270
			De-icer drag (percentage of smooth-wing drag)															
1	Normal	3 tubes inflated	132	125	124	132	[c]136	123	124	105	103	-	-	121	114	92	81	79
2	Normal	2 tubes inflated	99	103	95	93	[c]92	62	70	70	67	-	-	63	62	59	55	53
3	Normal	Deflated, normal	17	16	[b]33	[b]52	[b]57	20	15	[a]16	[b]26	[b]33	[b]34	27	22	18	[a]19	[b]22
4	Normal	Deflated, increased tension	17	15	[a]18	-	-	20	16	15	[a]16	-	-	29	22	17	14	13
5	Normal	Deflated, fabric backing	16	17	15	[a]16	[a,c]16	21	17	15	14	[a]15	[b]28	27	21	18	15	15
6	Flush	Deflated, normal surface, bulging prevented by cementing to wing	12	14	14	14	21	15	13	12	11	10	9	24	20	16	12	11
7	Flush	Deflated, smooth surface, bulging prevented by cementing to wing	1	7	10	10	10	8	9	10	9	8	7	19	17	13	11	9
8	Flush	Deflated, smooth doped surface, bulging prevented by cementing to wing	3	8	9	9	9	8	9	10	9	8	7	18	17	13	11	9

[a]Bulging has started.

[b]Bulging.

[c]Air speed 270 m.p.h.

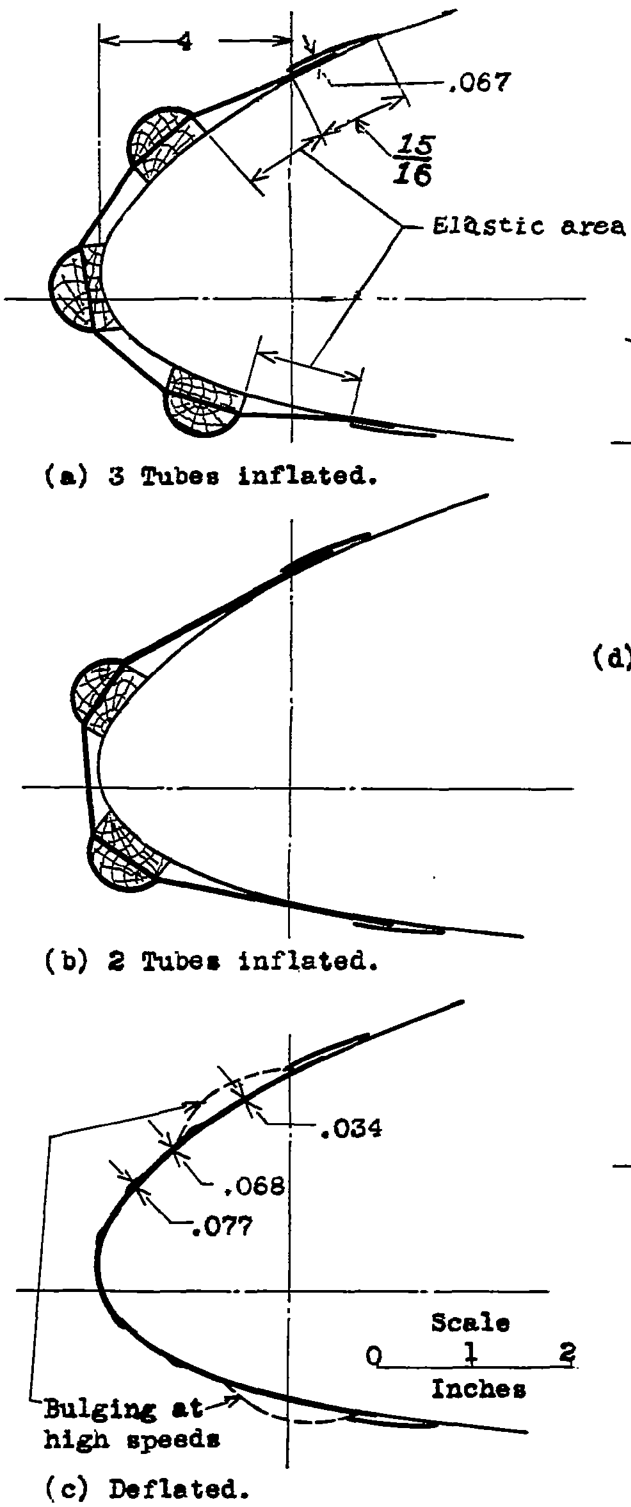

Figure 1.- Model de-icer profiles.